Cattle performance and production when grazing Bermudagrass at two forage mass levels in the southern Piedmont[1,2]

J. A. Stuedemann[3] and A. J. Franzluebbers[4]

J. Phil Campbell Sr. Natural Resource Conservation Center, Agricultural Research Service, USDA, Watkinsville, GA 30677

ABSTRACT: Performance and production of growing cattle (*Bos taurus*) on Coastal Bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture are affected by forage allowance, but possible interactions with fertilizer nutrient source (i.e., inorganic vs. organic) and time have not been well described. We evaluated the effects of 3 nutrient sources with equivalent N rates: 1) inorganic, 2) crimson clover (*Trifolium incarnatum* L.) cover crop plus inorganic, and 3) chicken (*Gallus gallus*) broiler litter, factorially arranged with 2 residual forage mass levels [grazing to maintain high (4,528 ± 1,803 kg/ha) and low (2,538 ± 1,264 kg/ha) forage mass], on cattle stocking density, ADG, and BW gain during 5 consecutive summer grazing seasons. Across grazing seasons, residual forage mass and nutrient source both affected response variables, but interactions between these variables were rarely significant ($P \leq 0.10$). Across grazing seasons and nutrient sources, increasing grazing pressure to maintain a lower forage mass reduced ADG (0.67 vs. 0.88 kg/d; $P < 0.001$) but increased BW gain/ha (726 vs. 578 kg/ha; $P < 0.001$) due to greater stocking density (8.7 vs. 5.8 steers/ha, $P < 0.001$; mean BW of growing Angus steers of 212 kg). Inorganic fertilization led to greater stocking density than other nutrient sources (8.2 vs. 6.8 steers/ha, $P < 0.001$) because of greater forage production. Stocking density to achieve the 2 targeted forage mass levels was widely different during the initial grazing seasons of the study but nearly similar at the end of 5 yr. Cattle performance tended to decline with time during each grazing season under both residual forage mass levels, perhaps as a result of declining forage quality, because performance was positively associated with grazing season precipitation under high forage mass. Steer BW gain/ha was greater ($P < 0.05$) with lower forage mass early in the grazing season of all years but not necessarily later in the grazing season. Steer BW gain/ha was also greater ($P < 0.05$) with a lower forage mass during the early years of the study but was similar during the later years of the study. Significant variations in cattle performance and production with time confirmed the short-term seasonal effects but suggested that the long-term effects may also be of importance in maintaining productivity and environmental quality of grazed pastures.

Key words: broiler litter, cattle production, daily gain, grazing pressure, inorganic fertilizer, stocking density

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INTRODUCTION

Coastal Bermudagrass [*Cynodon dactylon* (L.) Pers.] is an important warm-season perennial forage in the southeastern United States. Cattle performance and production on Bermudagrass hybrids have been widely studied in various environments and management conditions (Hill et al., 1993; Harvey et al., 1996; Wyatt et al., 1997). Although a general relationship between cattle performance and forage allowance is dependent on forage quality (Guerrero et al., 1984), considerable variation exists, suggesting that many external factors might influence cattle performance and production.

Nitrogen fertilizer is a necessary agronomic input for high forage-grass productivity and quality (Wilkinson and Langdale, 1974) but is energy intensive and costly; thus, alternatives are needed. Overseeding of Bermudagrass with crimson clover (*Trifolium incarnatum* L.) produced equivalent hay yield with half the inorganic N input required for Bermudagrass alone (Adams et al., 1967). Broiler litter is a locally abundant resource

[1]Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the USDA.

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[3]Retired.

[4]Corresponding author: afranz@uga.edu

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that can supply sufficient N at a reasonable cost, with many opportunities for application throughout the year (Wood et al., 1993; Evers, 1998). However, there is concern that its imbalance of N and P could threaten water quality from runoff (Pierzynski et al., 2000).

Short-term grazing studies (2 to 3 yr) are commonly used to evaluate the response of cattle production and performance to forage allowance (Guerrero et al., 1984; Hill et al., 1993; Aiken, 1998), but long-term effects need to be evaluated. A long-term study was designed to focus on the effects of fertilizer nutrient source and residual forage mass on soil and pasture properties (Franzluebbers et al., 2001, 2002, 2004a,b,c; Franzluebbers and Stuedemann, 2001, 2003a,b, 2005).

Our objective in this portion of the experiment was to determine cattle stocking density, performance, and production during the first 5 yr of Bermudagrass management.

MATERIALS AND METHODS

A 15-ha upland field (33° 22′ N, 83° 24′ W) near Farmington, GA, previously in conventional cultivation with wheat (*Triticum aestivum* L.), soybean [*Glycine max* (L.) Merr.], sorghum [*Sorghum bicolor* (L.) Moench], and cotton (*Gossypium hirsutum* L.) for several decades, was planted with Coastal Bermudagrass sprigs in 1991. Eighteen experimental units were arranged in a randomized complete block design, with 6 treatments in a split-plot arrangement in each of 3 blocks. The main plots were nutrient source, and the split-plots were residual forage mass level. The experiment also included hayed and unharvested exclosures (18 additional experimental units) that were not evaluated in this portion of the study (Franzluebbers et al., 2004c). The paddocks were 0.69 ± 0.03 ha. The spatial design of the paddocks minimized runoff contamination and facilitated handling of the cattle through a central roadway. Each paddock contained a 3 × 4 m shade, a mineral feeder, and a water trough, all placed in a line 15 m long at the greatest elevation.

Nutrient application was targeted to supply 200 kg of N/ha annually from 1 of 3 sources: 1) inorganic fertilizer as ammonium nitrate broadcast in split applications in May and July, 2) a crimson clover cover crop plus supplemental inorganic fertilizer with half of the targeted N supply assumed fixed by the clover biomass and the other half as ammonium nitrate broadcast in July, and 3) chicken broiler litter broadcast in split applications in May and July. Actual N application rates were 225 ± 19 kg of N/ha annually for inorganic, 135 ± 44 kg of N/ha (inorganic fraction only) annually for clover + inorganic, and 194 ± 26 kg of N/ha annually for broiler litter. The AU Robin crimson clover seed was peat-inoculated with *Rhizobium trifolii* and was no-tillage drilled into dormant Bermudagrass at 10 kg/ha in October of each year. We assumed that crimson clover fixed 110 kg of N/ha annually (Carreker et al., 1977). Phosphorus, K, and lime were applied differentially based on the broiler litter composition and soil testing (Franzluebbers et al., 2002, 2004a).

Residual forage mass levels were as follows: 1) high forage mass at a target of 3,000 kg/ha and 2) low forage mass at a target of 1,500 kg/ha. Yearling Angus steers (available herd of approximately 100 steers each grazing season; initial age of 14 mo; initial BW of 271 ± 13 kg; weaned 8 mo before stocking and wintered on pasture, hay, and grain to gain ≥0.5 kg/d) were allocated to paddocks for grazing beginning in mid-May, except in 1994 when stocking occurred in July due to repairs to infrastructure after a tornado. The steers grazed the paddocks until early October for a total of 140 d of grazing each year (84 d in 1994). No grazing occurred in the winter. Stocking density was based on achieving the target forage mass of each treatment using a put-and-take grazing system (Bransby, 1989), with 3 tester steers permanently assigned to each paddock within a grazing season and grazer steers added or removed at 28-d intervals. Forage mass was determined immediately before each animal handling event from 7 ± 1 fixed subsampling locations (0.25 m^2 each) within the experimental units by hand-clipping all aboveground forage to ground level and drying it at 55°C.

Procedures involving animals were approved by the local animal care and use committee. Tester steers were randomly selected from 3 groups of 18; 1 group closest, 1 group immediately heavier, and 1 group immediately lighter than the mean BW. All BW determinations were after 16 h without water while on the paddock. Grazer steers were assigned in a similar manner from the remaining pool of animals. Grazer steers not allocated to an experimental paddock grazed an adjacent pasture of similar forage. Daily forage intake was assumed to be 2.2% of BW (NRC, 1996). Franzluebbers et al. (2004c) contains details on nutrient application, forage management and production characteristics, and changes in pasture botanical composition with time. Forage allowance was calculated as the mean forage mass (immediately before and after a grazing period) divided by the mean animal BW (initial and ending BW) of each paddock divided by the number of grazing days (28 d).

Before stocking in May, all steers received the following anthelmintic treatment: pour-on ivermectin (Ivomec, Merial Ltd., Iselin, NJ) 21 d before stocking, albendazole (Valbazen, Pfizer, New York, NY) 7 d before stocking, and injectable ivermectin (Ivomec, Merial Ltd.) 2 d before stocking. The steers remained in drylot for 2 d before stocking. No further anthelmintic treatments occurred during the remainder of the grazing season.

On initial stocking and restocking days, steers were released into the central roadway early in the morning and corralled together to be weighed. Steer BW was recorded from a digital balance under a chute. Steers were returned to their paddocks mostly within 2 h of corralling.

Steer BW gain/ha was calculated as the difference in initial and final BW of the tester steers, with proportionality adjustments for the total number of steers on a paddock during a grazing period. Steer ADG was calculated from the difference in initial and final BW of the tester steers divided by the number of grazing days. Stocking density was calculated as the number of steers on a pasture divided by the paddock size (0.65 to 0.75 ha). Steer BW stocked/ha was calculated from the average BW of all steers on the paddock (from initial and final BW).

The response variables were analyzed for variance within individual months and across the entire summer grazing season using the GLM procedure (SAS Inst. Inc., Cary, NC). With the split-plot arrangement of treatments, replication × nutrient source was the error term for the nutrient source effect, and replication × nutrient source × residual forage mass was the error term for residual forage mass and nutrient source × residual forage mass effects. Grazing season effects were considered a further split-plot in time and were evaluated with the experiment-wise error term. Covariance among grazing seasons was small, and therefore, a mixed model did not improve on GLM. Precipitation was hypothesized as a factor to explain differences among grazing seasons, and therefore, the response variables were regressed on precipitation to elucidate significant relationships. All effects were considered significant at $P \leq 0.10$. Although this seemed to be a lenient probability level, we did not want to overlook potentially important trends. Actual P-levels were also reported for many of the effects in the tables.

RESULTS AND DISCUSSION

Environmental Conditions

The summer grazing season in northern Georgia is characterized, on average, by relatively warm and moist climatic conditions with relatively uniform precipitation from April to September (101 ± 11 mm/mo; Table 1). Precipitation from May to September (579 ± 180 mm) varied considerably among grazing seasons. Driest periods of each grazing season were April to May in 1994, July in 1995, May to June in 1996, August in 1997, and July in 1998. Except for May and July, there were also months that received double the mean precipitation, including June, August, and September of 1994 and April of 1998. Cumulative May to September precipitation had a CV of 33% among grazing seasons, whereas individual months during the grazing season had greater CV, ranging from 33% in May to 61% in July. Therefore, months with extreme precipitation during a grazing season were often balanced with months of opposite extreme within the same grazing season.

Forage mass was intentionally (because of the experimental design) different throughout the grazing season, except in April before grazing (Table 2). Across each month and grazing season, forage mass averaged 4,528 and 2,538 kg/ha. These levels were greater than targeted but occurred because of uncertain precipitation before stocking, limited herd size, and a desire to avoid overgrazing.

Abundant winter annual grasses and clover provided the forage mass during the winter and early spring to negate intentional forage mass differences in April. We did not control for winter annual grasses, and they can be a significant, high-quality forage component of Bermudagrass pastures. Paddocks were mowed to a 10-cm height after the April forage mass determination each grazing season. Forage mass was greater with clover + inorganic than other nutrient source treatments in May and September but less than other nutrient source treatments in June and July. Decomposition of N-rich clover biomass may have stimulated forage growth in early spring before inorganic or broiler litter fertilization. Maximum conversion efficiency of applied N to forage DM yield was estimated at approximately 200 kg of N/ha annually for Coastal Bermudagrass (Overman and Wilkinson, 1992), which was also the approximate breakpoint for susceptibility to N leaching loss on these soils (Wilkinson and Frere, 1993).

Stocking Density and Weight

Across grazing seasons, cattle stocking density was always greater with low than with high forage mass during each month, as an intended consequence of management (Table 3). Within and among grazing seasons, stocking density was 50% greater with low than with high forage mass. Among months of the grazing season under high forage mass, stocking density increased from a low of 4.6 steers/ha in May to 6.2 ± 0.2 steers/ha in July to September. Under low forage mass, stocking density was relatively stable at 8.5 ± 0.7 steers/ha among months of the grazing season.

Stocking density varied somewhat among grazing seasons but more so among months within a grazing season (data not shown). Stocking density was relatively uniform during the grazing seasons of 1994 and 1995 but increased with time during the grazing season in 1996 because of greater-than-normal precipitation in August and September. Stocking density declined with time during the grazing season of 1998 because of lower-than-normal precipitation after April.

Stocking density varied among grazing seasons with respect to residual forage mass (Table 3). Some of the variation in stocking density among grazing seasons could be explained by precipitation (similar to BW stocked/ha in Figure 1). With low forage mass, precipitation was a good predictor of stocking density in July and when averaged across the grazing season. Increasing precipitation increased stocking density as a result of increased forage growth. In contrast, precipitation had no effect on stocking density under conditions of high forage mass. The reason for this lack of response to precipitation was unclear. Minimum difference in stocking density occurred between residual forage mass levels when precipitation was low, and maximum difference occurred with high precipitation.

Table 1. Climatic conditions during the 1994 to 1998 study period near Farmington, GA, and over the long-term (1945 to 2003, Athens, GA, airport)

	Month												
Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Temperature, °C													
Long-term mean daily low	0.7	1.9	5.4	9.7	14.4	18.6	20.6	20.1	17.0	10.5	5.3	1.6	10.5
Long-term mean daily high	11.4	13.7	17.8	22.9	27.0	30.4	31.8	31.2	28.0	23.0	17.5	12.5	22.3
Precipitation, mm													
Long-term mean	119	112	133	96	104	105	124	90	92	79	93	99	1,246
1994	102	84	139	54	47	282	165	188	196	184	83	52	1,576
1995	134	161	67	168	112	152	14	166	77	165	117	76	1,409
1996	187	85	196	95	66	79	96	144	115	19	82	82	1,246
1997	133	203	38	136	65	137	169	47	175	196	99	159	1,557
1998	165	213	135	194	81	76	81	55	81	68	54	50	1,253

Across the grazing season, stocking density was greater with inorganic than with clover + inorganic and broiler litter fertilization (Table 3). However, nutrient source did not affect stocking density either early in the grazing season (May) or at the end of the grazing season (September). From June to August, stocking density followed the order: inorganic > broiler litter > clover + inorganic. It appears that inorganic fertilization gave the most immediate forage growth response, as expected, and therefore, stocking density was greater in those periods immediately following fertilization (May and July).

The effect of nutrient source on stocking density varied among grazing seasons (Table 3). Typically, most grazing seasons were consistent with the overall mean, but there were also occasional seasons that deviated.

Steer BW stocked/ha responded to treatments in a similar manner as stocking density but was different primarily within monthly comparisons due to BW gain that occurred throughout the grazing season. Mean

Table 2. Actual forage mass at the beginning of the monthly period as affected by nutrient source and targeted forage mass treatment from 1994 to 1998 at Farmington, GA

Nutrient source	Residual forage mass	Month: Apr	May	Jun	Jul	Aug	Sep	Oct
		kg/ha						
Inorganic[1]	High	3,112	3,523	4,562	6,017	5,559	5,318	4,765
Inorganic	Low	3,208	3,250	2,971	3,057	2,412	1,913	2,034
Clover + inorganic[2]	High	2,623	4,429	3,423	4,036	4,891	5,730	4,735
Clover + inorganic	Low	3,550	3,875	1,844	2,077	2,312	2,705	1,830
Broiler litter[3]	High	3,057	3,629	4,247	4,897	4,990	5,098	5,091
Broiler litter	Low	2,818	2,773	2,450	2,443	2,421	2,141	2,062
LSD (P = 0.10) among nutrient × forage mass means		629	437	295	431	638	502	388
Inorganic	Mean	3,160	3,386	3,767	4,537	3,986	3,616	3,400
Clover + inorganic	Mean	3,087	4,152	2,634	3,057	3,601	4,218	3,283
Broiler litter	Mean	2,937	3,201	3,348	3,670	3,705	3,620	3,576
LSD (P = 0.10) among nutrient means		391	382	243	298	514	471	278
Mean	High	2,931	3,860	4,077	4,984	5,146	5,382	4,864
Mean	Low	3,192	3,300	2,422	2,525	2,382	2,253	1,975
LSD (P = 0.10) among forage mass means		363	252	171	249	368	290	224
CV, %		18	10	15	20	16	18	18
Source of variation	**df**	***P*-value**						
Nutrient source	2	0.52	0.01	0.001	0.001	0.35	0.08	0.19
Forage mass	1	0.21	0.005	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × forage mass	2	0.10	0.26	0.56	0.05	0.42	0.47	0.60
Year	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × year	8	0.03	<0.001	<0.001	0.02	0.003	0.10	0.22
Forage mass × year	4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × forage mass × year	8	0.51	<0.001	0.60	0.57	0.87	0.06	0.12

[1]Inorganic fertilizer applied as ammonium nitrate in May and July.
[2]Crimson clover cover crop plus ammonium nitrate applied in July.
[3]Broiler litter applied in May and July.

Table 3. Steer stocking density sorted by month and averaged across the year as affected by nutrient source and residual forage mass level from 1994 to 1998 at Farmington, GA

Nutrient source	Residual forage mass	May	Jun	Jul	Aug	Sep	Yearly
		steers/ha					
Inorganic[1]	High	4.5	6.9	8.0	7.4	7.0	6.8
Inorganic	Low	10.0	10.0	10.2	9.1	7.2	9.5
Clover + inorganic[2]	High	4.8	5.0	4.7	5.2	7.1	5.2
Clover + inorganic	Low	10.2	6.7	6.0	7.2	9.4	8.0
Broiler litter[3]	High	4.4	6.2	6.2	5.7	5.3	5.5
Broiler litter	Low	8.9	8.7	7.7	8.4	7.7	8.5
LSD (P = 0.10) among nutrient × forage mass means		1.0	0.8	0.9	0.7	1.1	0.4
Inorganic	Mean	7.3	8.5	9.1	8.2	7.1	8.2
Clover + inorganic	Mean	7.5	5.9	5.3	6.2	8.3	6.6
Broiler litter	Mean	6.7	7.5	6.9	7.0	6.5	7.0
LSD (P = 0.10) among nutrient means		1.0	0.7	0.5	0.8	1.5	0.5
Mean	High	4.6	6.0	6.3	6.1	6.5	5.8
Mean	Low	9.7	8.5	7.9	8.2	8.1	8.7
LSD (P = 0.10) among forage mass means		0.6	0.5	0.5	0.4	0.6	0.2
CV, %		11	14	21	16	20	7
Source of variation	**df**	***P*-value**					
Nutrient source	2	0.32	0.004	<0.001	0.02	0.14	0.006
Forage mass	1	<0.001	<0.001	<0.001	<0.001	0.002	<0.001
Nutrient source × forage mass	2	0.44	0.19	0.41	0.22	0.05	0.52
Year	4[4]	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × year	8[5]	0.04	0.13	0.04	<0.001	0.004	<0.001
Forage mass × year	4[4]	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × forage mass × year	8[5]	0.43	0.37	0.06	0.02	0.005	0.08

[1]Inorganic fertilizer applied as ammonium nitrate in May and July.
[2]Crimson clover cover crop plus ammonium nitrate applied in July.
[3]Broiler litter applied in May and July.
[4]Except for May and June, for which df = 3.
[5]Except for May and June, for which df = 6.

steer BW was 272 ± 13 kg in May, 294 ± 26 kg in June, 304 ± 24 kg in July, 321 ± 23 kg in August, and 338 ± 21 kg in September. Steer BW stocked/ha with low forage mass averaged 41% greater than with high forage mass across grazing seasons (Table 4). Experimental CV was slightly lower with BW stocked/ha than with stocking density, suggesting that BW stocked/ha would be a more experimentally sensitive response variable related to forage consumption.

Difference in BW stocked/ha between residual forage mass levels was greater earlier than later in the grazing season (Table 4). Across grazing seasons, BW stocked/ha with low forage mass was 106% greater than with high forage mass in May, 40% greater in June, 19% greater in July, 28% greater in August, and 21% greater in September. Within individual months and grazing seasons, BW stocked/ha was not always greater with low than with high forage mass (Figure 2). Greater BW stocked/ha with low than with high forage mass occurred in 3 of 3 mo in 1994, in 4 of 5 mo in 1995, in 1 of 5 mo in 1996, in 4 of 5 mo in 1997, and in 2 of 5 mo in 1998. It appears that less utilization of Bermudagrass early in the grazing season with the high-forage-mass treatment simply allowed accumulation of forage mass without greatly affecting the relationship between production of forage and consumption by cattle later in the grazing season.

Stocking density and BW stocked/ha were affected (P < 0.001) by the interaction of residual forage mass with grazing season (Tables 3 and 4). Steer BW stocked/ha declined with increasing number of grazing seasons under low forage mass and remained relatively stable across grazing seasons under high forage mass, resulting in larger differences earlier than later in the study (Figure 1). Further evaluation of these systems will be needed to determine if feedback between stocking density and forage production might further reverse the major residual forage mass effects that were initially observed and consistent with the literature of other short-term studies (Guerrero et al., 1984; Bates et al., 1996).

Interaction between residual forage mass and nutrient source on cattle stocking density and BW stocked/ha was mostly not significant within months, across grazing season, and among grazing seasons (Tables 3 and 4). This consistency in stocking density and BW stocked/ha between residual forage mass and nutrient sources indicates that alternative nutrient sources did not significantly affect forage production-animal consumption relationships.

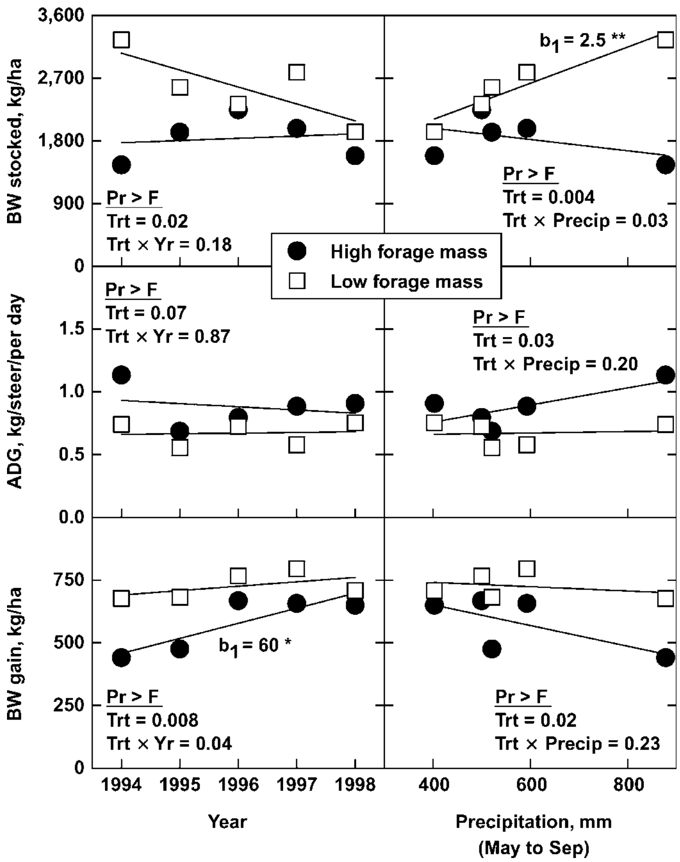

Figure 1. Relationships of time (experimental year) and grazing-season precipitation to annual steer BW stocked/ha, ADG, and BW gain/ha as affected by residual forage mass averaged across nutrient sources near Farmington, GA. * and **Significance of the slope coefficient at $P <$ 0.05 and 0.01, respectively. Trt = forage mass treatment; Yr = year; Precip = precipitation; Pr > F = probability of achieving a greater F value.

ADG

Steer ADG was 24% less with low than with high forage mass across grazing seasons (Table 5). However, significant seasonal variation in ADG occurred, in which August provided a direct contrast to all other months. Steer ADG in August was 12% greater under low than high forage mass. Steer ADG with low forage mass was 47 to 81% of that with high forage mass in other months. An interaction ($P < 0.10$) between nutrient source and residual forage mass occurred in May (greater relative forage mass effect with clover + inorganic fertilization compared with other nutrient source treatments) and in September (large forage mass effect with clover + inorganic and broiler litter fertilization but no forage mass effect with inorganic fertilization).

The effect of residual forage mass on ADG varied among grazing seasons (Table 5). Precipitation among grazing seasons explained some of the interaction of residual forage mass × year, especially when precipitation was summed across the grazing season (Figure 1). Difference in ADG between residual forage mass levels was low when precipitation was low, and the difference increased with increasing precipitation. This effect was due to a positive response of ADG to precipitation with high forage mass, perhaps because of more succulent secondary shoot growth from the many above-ground stems with high forage mass. July provided the only positive response in ADG to precipitation, but no difference in response occurred between residual forage mass levels.

Within individual months and grazing seasons, ADG was variably affected by residual forage mass (Figure 2). Lower ADG with low than with high forage mass occurred in 2 of 3 mo in 1994, in 3 of 5 mo in 1995, in 2 of 5 mo in 1996, in 4 of 5 mo in 1997, and in 3 of 5 mo in 1998. Greater ADG with low than with high forage mass occurred in August of 1995 and 1998. In both of these cases, precipitation during the previous month of July was low, which may have resulted in subsequently greater forage quality. Steer ADG was often greatest within a grazing season in May, probably as a result of greater forage quality (Harvey et al., 1996). Performance of beef cattle can also be improved with application of anthelmintics (Ball, 1997), and this effect may have enhanced ADG early in the grazing season as well. Loss of BW occurred in July 1995 and September 1997 in both residual forage mass treatments, which appears to have been due to heat stress, very low precipitation in July 1995 and in August 1997 that limited forage production and quality, or both.

Steer ADG across months and grazing seasons was greater with clover + inorganic fertilization than with inorganic only or broiler litter fertilization (Table 5). This effect was mostly from observations in July and August. In May, ADG followed the following order: inorganic > broiler litter > clover + inorganic. In June, there was no nutrient source effect on ADG. In September, ADG was greater with inorganic and clover + inorganic than with broiler litter fertilization. The effect of nutrient source on ADG varied relatively little among grazing seasons for any particular month except in May and when averaged across the grazing season (Table 5).

The 5-yr mean ADG (0.67 kg/d) of steers grazing Coastal Bermudagrass managed with low forage mass (2,538 ± 1,264 kg/ha) in our study was similar to the 3-yr mean ADG (0.65 to 0.67 kg/d) of steers grazing Tifton 78 and Tifton 85 Bermudagrass maintained at approximately 2,400 kg/ha in southern Georgia during 169 d in the summer (Hill et al., 1993). With high forage mass, ADG in our study was exceptionally high (0.88 kg/d) and may have been related to the greater leaf selectivity allowed to animals with abundant forage (4,528 ± 1,803 kg/ha).

Daily forage allowance was 101 ± 43 g of forage/kg of BW under high forage mass and 33 ± 12 g of forage/kg of BW under low forage mass. Clover + inorganic tended to have greater forage allowance than inorganic fertilization, although average differences were only 17 and 6 g of forage/kg of BW under low and high forage

Table 4. Steer BW stocked/ha sorted by months and averaged across the year as affected by nutrient source and residual forage mass level from 1994 to 1998 at Farmington, GA

Nutrient source	Residual forage mass	May	Jun	Jul	Aug	Sep	Yearly
		kg/ha					
Inorganic[1]	High	1,262	2,009	2,454	2,414	2,369	2,122
Inorganic	Low	2,690	2,900	2,891	2,797	2,386	2,795
Clover + inorganic[2]	High	1,309	1,442	1,488	1,721	2,432	1,660
Clover + inorganic	Low	2,681	1,947	1,772	2,248	3,061	2,380
Broiler litter[3]	High	1,219	1,868	1,935	1,857	1,835	1,725
Broiler litter	Low	2,394	2,564	2,270	2,573	2,531	2,538
LSD (P = 0.10) among nutrient × forage mass means		262	342	285	210	264	111
Inorganic	Mean	1,976	2,455	2,673	2,605	2,377	2,459
Clover + inorganic	Mean	1,995	1,694	1,630	1,985	2,747	2,020
Broiler litter	Mean	1,806	2,216	2,103	2,215	2,183	2,131
LSD (P = 0.10) among nutrient means		267	143	148	221	430	131
Mean	High	1,263	1,773	1,959	1,998	2,212	1,836
Mean	Low	2,588	2,470	2,311	2,539	2,659	2,571
LSD (P = 0.10) among forage mass means		151	198	165	121	152	64
CV, %		10	13	19	16	19	7
Source of variation	**df**	***P*-value**					
Nutrient source	2	0.35	<0.001	<0.001	0.01	0.11	0.005
Forage mass	1	<0.001	<0.001	0.006	<0.001	0.001	<0.001
Nutrient source × forage mass	2	0.43	0.36	0.76	0.17	0.02	0.29
Year	4[4]	<0.001	0.002	<0.001	<0.001	<0.001	<0.001
Nutrient source × year	8[5]	0.04	0.19	0.14	0.005	0.008	0.003
Forage mass × year	4[4]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × forage mass × year	8[5]	0.36	0.22	0.18	0.05	0.04	0.18

[1]Inorganic fertilizer applied as ammonium nitrate in May and July.
[2]Crimson clover cover crop plus ammonium nitrate applied in July.
[3]Broiler litter applied in May and July.
[4]Except for May and June, for which df = 3.
[5]Except for May and June, for which df = 6.

mass treatments, respectively. On Blackland soil in eastern Texas, strong quantitative relationships were reported between ADG and forage allowance (Guerrero et al., 1984). Although we observed similar ranges in ADG and forage allowance as the cited study, strong relationships were not evident in our data, suggesting that variables other than forage allowance influenced ADG to a larger extent. Using the relationships reported in Guerrero et al. (1984), expected ADG under the mean forage allowances in our study would have been 1.06 kg/d under high forage mass and 0.63 kg/d under low forage mass, assuming high forage quality (>60% digestible DM) and 0.83 and 0.33 kg/d, respectively, assuming medium forage quality (53 to 60% digestible DM). We did not measure digestible DM in our study, but using the relationships of Guerrero et al. (1984), forage quality would have to be considered of medium quality with high forage mass and of high quality with low forage mass. Determination of forage C/N ratio at the beginning and end of each grazing season corroborated this interpretation, where forage C/N ratio was 26 ± 4 g/g under high forage mass and 21 ± 2 g/g under low forage mass (Franzluebbers et al., 2004c).

Steer BW Gain/ha

Steer BW gain/ha was 26% greater (P < 0.001) with low than with high forage mass, when averaged across months and grazing seasons (Table 6). However, BW gain/ha with low forage mass was 76% greater (P < 0.001) in May, 21% less (P = 0.04) in June, 20% greater (P = 0.13) in July, 54% greater (P = 0.001) in August, and 33% less (P = 0.04) in September than with high forage mass. Greatest BW gain/ha was achieved in May and August with low forage mass (>200 kg/ha per mo). Lowest BW gain/ha occurred in September in both residual forage mass treatments (<70 kg/ha per mo), probably as a result of limited forage regrowth from cooler temperature and declining forage quality with maturation.

Significant variation in BW gain/ha as a function of residual forage mass occurred among grazing seasons (Table 6). The residual forage mass × grazing season interaction was only weakly described by variation in precipitation among grazing seasons, similar to that observed for ADG (data not shown). Significant relationship of BW gain/ha with precipitation only occurred in July and when averaged across the grazing season.

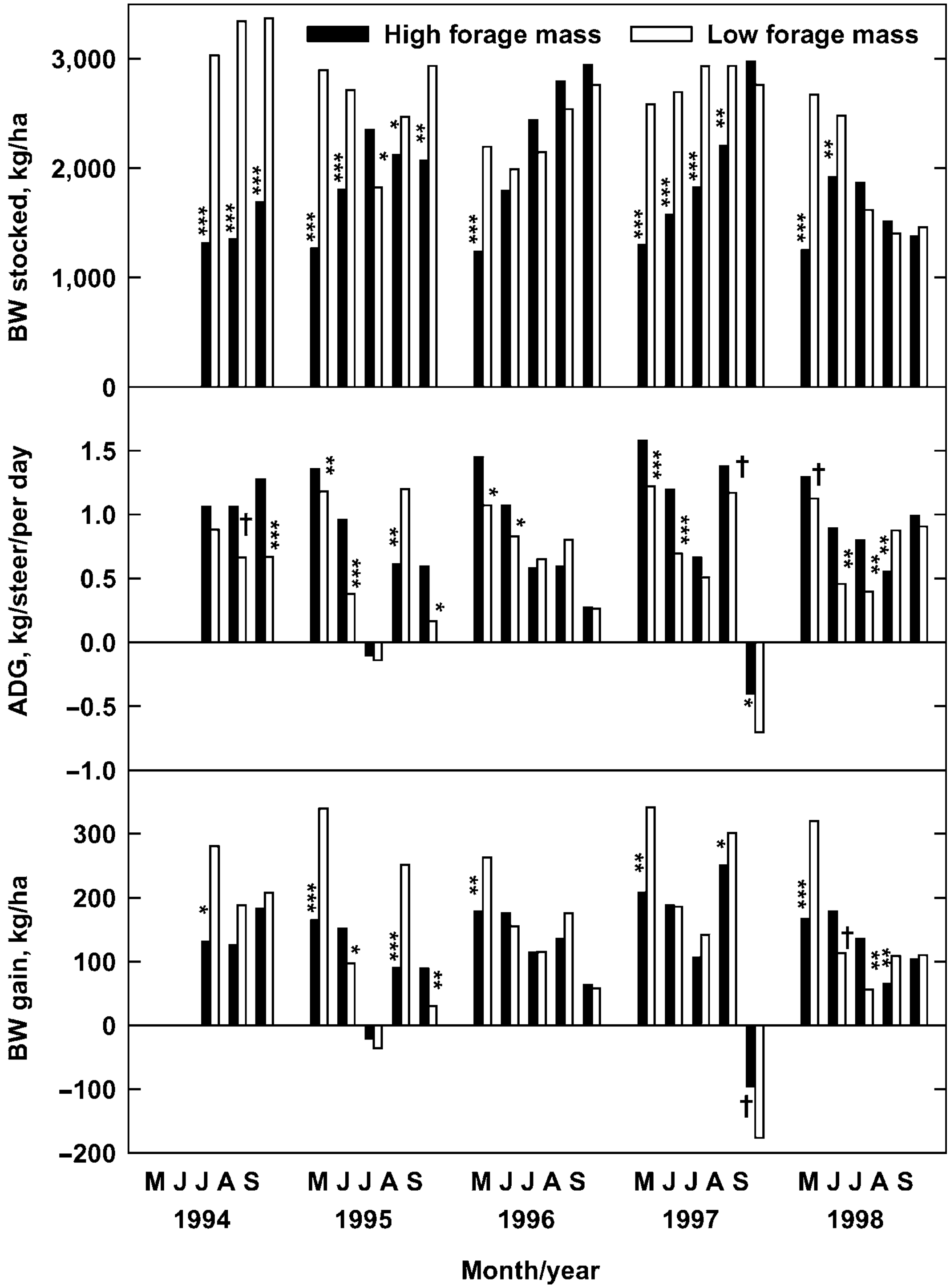

Figure 2. Monthly variation among grazing seasons in steer BW stocked/ha, ADG, and BW gain/ha as affected by residual forage mass averaged across nutrient sources near Farmington, GA. †, *, **, and ***Significance between residual forage mass level means during a month at $P < 0.10$, 0.05, 0.01, and 0.001, respectively.

Steer BW gain/ha was positively related to July precipitation in both residual forage mass treatments. Even by including precipitation of the previous month, relationship of BW gain/ha to precipitation was not improved in August but was somewhat improved in September. Contrasting to the results of stocking density and ADG, cumulative BW gain/ha during the grazing season was negatively related with precipitation under high forage mass (Figure 1).

Within individual months and grazing seasons, BW gain/ha was variably affected by residual forage mass level (Figure 2). Significant effects of residual forage mass on BW gain/ha occurred among some months in all grazing seasons (i.e., 1 positive month in 1994, 2

Table 5. Steer ADG sorted by months and across the year as affected by nutrient source and residual forage mass level from 1994 to 1998 at Farmington, GA

Nutrient source	Residual forage mass	May	Jun	Jul	Aug	Sep	Yearly
		kg/d					
Inorganic[1]	High	1.52	1.04	0.60	0.68	0.48	0.85
Inorganic	Low	1.35	0.60	0.37	0.76	0.41	0.67
Clover + inorganic[2]	High	1.35	1.01	0.73	1.06	0.67	0.97
Clover + inorganic	Low	0.87	0.53	0.62	1.18	0.25	0.71
Broiler litter[3]	High	1.38	1.03	0.47	0.78	0.48	0.82
Broiler litter	Low	1.23	0.64	0.38	0.89	0.12	0.63
LSD (P = 0.10) among nutrient × forage mass means		0.17	0.12	0.22	0.13	0.17	0.05
Inorganic	Mean	1.44	0.82	0.49	0.72	0.45	0.76
Clover + inorganic	Mean	1.11	0.77	0.68	1.12	0.46	0.84
Broiler litter	Mean	1.31	0.83	0.42	0.83	0.30	0.72
LSD (P = 0.10) among nutrient means		0.09	0.08	0.13	0.11	0.14	0.06
Mean	High	1.42	1.03	0.60	0.84	0.55	0.88
Mean	Low	1.15	0.59	0.46	0.94	0.26	0.67
LSD (P = 0.10) among forage mass means		0.10	0.07	0.13	0.07	0.10	0.03
CV, %		15	26	49	33	55	13
Source of variation	**df**	P-value					
Nutrient source	2	0.004	0.26	0.03	0.003	0.13	0.02
Forage mass	1	0.002	<0.001	0.08	0.04	0.001	<0.001
Nutrient source × forage mass	2	0.06	0.54	0.69	0.87	0.07	0.12
Year	4[4]	0.03	<0.001	<0.001	<0.001	<0.001	<0.001
Nutrient source × year	8[5]	0.31	0.28	0.48	0.11	0.49	0.02
Forage mass × year	4[4]	0.20	0.12	0.09	<0.001	0.001	<0.001
Nutrient source × forage mass × year	8[5]	0.49	0.33	0.73	0.79	0.02	0.41

[1]Inorganic fertilizer applied as ammonium nitrate in May and July.
[2]Crimson clover cover crop plus ammonium nitrate applied in July.
[3]Broiler litter applied in May and July.
[4]Except for May and June, for which df = 3.
[5]Except for May and June, for which df = 6.

positive and 2 negative months in 1995, 1 positive month in 1996, 2 positive months and 1 negative month in 1997, and 2 positive and 2 negative months in 1998). Statistically greater BW gain/ha with low than with high forage mass occurred in all grazing seasons but was tempered by reversal of effects during some months in 1995, 1997, and 1998. Greatest BW gain/ha was achieved during the early part of each grazing season, probably as a result of high forage quality and immediate response to anthelmintic treatment. Although an anthelmintic treatment was administered only in May of each grazing season, gastrointestinal nematode eggs were kept at low levels throughout the grazing season due to prevention of incoming larvae (Stuedemann et al., 2004).

The difference in BW gain/ha between residual forage mass levels was greatest during early grazing seasons of this study, suggesting that pasture productivity due to residual forage mass was changing with time (Figure 1). A shift in botanical composition of pastures with time (Franzluebbers et al., 2004c) appears to have manifested itself in a feedback loop, in which greater grazing pressure (i.e., low forage mass) eventually reduced the difference in forage and cattle production. The temporal results of BW stocked/ha and, to a lesser extent, ADG, corroborate this feedback on system productivity. However because precipitation was negatively correlated with number of grazing seasons in this study ($r = -0.77$), separation of grazing pressure feedback and precipitation on cattle performance and productivity was not entirely clear. A longer-term evaluation of these systems is warranted to verify relationships.

Steer BW gain/ha was greater with inorganic than broiler litter fertilization when averaged across months of each grazing season (Table 6). Variation in BW gain/ha among months in response to nutrient source also occurred. Steer BW gain/ha was greater with inorganic than clover + inorganic fertilization in May and June, was lower in August, and was not different in July and September. Steer BW gain/ha was greater with clover + inorganic than with broiler litter fertilization in August and September, was lower in June, and was not different in May and July. Variation in BW gain/ha in response to nutrient source also occurred among grazing seasons (Table 6), but effects were not dramatic.

The 5-yr mean BW gain/ha of steers grazing Coastal Bermudagrass managed with low forage mass in our study (726 kg/ha) was similar to the 3-yr mean BW gain/ha (789 kg/ha) for steers grazing Tifton 78 but lower than BW gain/ha (1,156 kg/ha) for steers grazing

Table 6. Steer BW gain/ha sorted by month and summed across the year as affected by nutrient source and residual forage mass level from 1994 to 1998 at Farmington, GA

Nutrient source	Residual forage mass	May	Jun	Jul	Aug	Sep	Yearly
		kg/ha					
Inorganic[1]	High	191	202	119	134	65	632
Inorganic	Low	380	164	130	184	51	800
Clover + inorganic[2]	High	179	142	85	153	93	587
Clover + inorganic	Low	257	95	112	243	67	704
Broiler litter[3]	High	169	177	76	113	48	513
Broiler litter	Low	312	154	93	188	19	673
LSD (P = 0.10) among nutrient × forage mass means		47	45	36	37	29	56
Inorganic	Mean	285	183	124	159	58	716
Clover + inorganic	Mean	218	118	98	198	80	645
Broiler litter	Mean	241	166	85	150	34	593
LSD (P = 0.10) among nutrient means		42	20	44	26	41	97
Mean	High	179	174	93	133	69	578
Mean	Low	316	138	112	205	46	726
LSD (P = 0.10) among forage mass means		28	26	21	21	17	32
CV, %		20	33	58	35	111	13
Source of variation	**df**	***P*-value**					
Nutrient source	2	0.06	0.005	0.26	0.04	0.17	0.12
Forage mass	1	<0.001	0.04	0.13	0.001	0.04	<0.001
Nutrient source × forage mass	2	0.05	0.75	0.81	0.39	0.79	0.45
Year	4[4]	0.02	0.006	<0.001	<0.001	<0.001	<0.001
Nutrient source × year	8[5]	0.05	0.47	0.01	0.03	0.32	0.05
Forage mass × year	4[4]	0.06	0.23	<0.001	0.02	0.08	0.02
Nutrient source × forage mass × year	8[5]	0.52	0.45	0.52	0.90	0.02	0.15

[1]Inorganic fertilizer applied as ammonium nitrate in May and July.
[2]Crimson clover cover crop plus ammonium nitrate applied in July.
[3]Broiler litter applied in May and July.
[4]Except for May and June, for which df = 3.
[5]Except for May and June, for which df = 6.

Tifton 85 Bermudagrass in southern Georgia during 169 d (Hill et al., 1993). In this previous study, forage production in adjacent hayed small plots was high (11,000, 11,300, and 14,700 kg/ha for Coastal, Tifton 78, and Tifton 85, respectively) because of the longer grazing season (Hill et al., 1993). Forage production in our study under hayed management was 7,519 ± 2,132 kg/ha among grazing seasons and nutrient sources (Franzluebbers et al., 2004c). Therefore, the estimated quantity of available forage converted to BW gain/ha tended to be equal or greater in our study (7.7 and 9.7% under high and low forage mass, respectively) than in the study of Hill et al. (1993; 7.0% under Tifton 78 and 7.9% under Tifton 85).

In conclusion, the lack of interaction between residual forage mass and nutrient source treatments suggested that regardless of how nutrients were supplied to the pasture, forage management for optimal cattle production should be the same. During early years of this 5-yr study, low forage mass supported greater stocking density, lower ADG, and greater BW gain/ha than high forage mass. However, changes occurred with time. At the end of 5 yr, stocking density, ADG, and BW gain/ha became more similar, suggesting a negative feedback from the high grazing pressure on forage production and subsequent cattle production. Inorganic fertilization allowed greater stocking density and led to greater BW gain/ha than broiler litter fertilization. Significant variations in cattle performance and production with time confirmed short-term seasonal effects but suggest that long-term cumulative effects may also be of importance in maintaining productivity and environmental quality of grazed pastures.

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